Integrated Superconducting Heterodyne Receivers at Submillimeter Wavelengths for Detailed Molecular Investigation of Extra-solar Planetary Atmospheres

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Since the recent detection of extra-solar planets, there has been a growing interest in the possibilities of inferring the presence of life or at least of a prebiotic chemistry on these worlds, via the detection of certain sets of molecules in their atmospheres: H_2O, O_2, O_3, CH_4, N_2O. (*Lovelock*, 1965; *Angel, Chen, and Woolf*, 1986; *Léger, Pirre, and Marceau*, 1993; *Kasting*, 1997). Some of these trace gases can theoretically be detected as absorption lines in the NIR part of the planet's blackbody spectrum, and this will be the primary goal of such space missions as TPF/Darwin. However, heterodyne detection at submillimeter wavelengths of some of these molecules and of others will be a valuable, if not crucial, complement to TPF/Darwin observations for the following reasons: 1) certain tracers, e.g. CH_4, N_2O, may require a higher spectral resolution than can be achieved at the short wavelengths, typically $\sim$ 10–1000; 2) additional molecules which may not be observable as NIR absorption bands should consolidate the evidence for life / absence of life, especially as progress is made in the understanding of life in the framework of geophysics and environment sciences; and 3) the fine study of atmospheric molecular line shapes in the mm/submm wave range will provide essential data on temperature, density, and abundances. Furthermore, in spite of the low submm-wave flux involved, the contrast between the star and the extrasolar planet is much more favorable at these frequencies. It will probably be possible within this decade to detect some of these submm lines from the ground using the interferometer ALMA, thanks to its unrivaled collecting area and angular resolution. Yet other molecular species related to exobiology, such as water and many hydrides, will only be detected in extrasolar planets within a 15-pc radius by submm-wave space interferometric missions with very large collecting areas and very long baselines. Such submm-wave interferometers in space are already being discussed as post-Herschel candidate space projects, for mapping "cold" sources (e.g. galactic molecular clouds) with a high angular resolution in the submm and THz range. We present in this paper a novel technology using integrated superconducting submillimeter-wave receivers, perfectly suited to this type of mission. The highly compact, lightweight, low power consumption, and broadband (several hundreds of GHz) receivers will allow the coverage of numerous molecular lines from 100 to 800 GHz, with near-quantum limited sensitivity. Each receiver consists of a single chip combining a submm-wave antenna on membrane, a wideband SIS mixer, a wide-tuning Josephson submm-wave local oscillator (LO), and a cryogenic HEMT or SQUID amplifier for the intermediate frequency. Using these on-chip receivers offers many advantages: reliability is increased, and cryogenic power requirements are greatly reduced, so that small space-qualified cryocoolers can be envisioned. Phase reference and synchronization of the LOs can be achieved using optical links between the satellites (for phase-lock and positioning telemetry), and the IF signals from all satellites will modulate optical carriers sent to a digital correlator aboard a combiner-satellite. The spectral resolution can be 10^6–10^7 or more. We present the concept behind these novel receivers, along with recent experimental results using a unique design and technology developed at LERMA. A receiver prototype is being developed, aimed at the high spectral resolution detection of water (557 GHz).

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